A Third Party Logistics Provider for the Best Selection in Fuzzy Dynamic Decision Environments

Ziping Chiang and Gwo-Hshiung Tzeng

Abstract

For minimizing total cost and maximizing the efficiency of resource use, the outsourcing of logistics has become one of the hot topics being seriously discussed in the last few years. Enterprises have an urgent requirement to choose a suitable third party logistic (3PL) provider in flexible business. Therefore, this paper uses the modified fuzzy analytic hierarchy process method to find a 3PL for supplier selection problem in fuzzy dynamic decision environments. For estimating the logistics vendors' past, present and near future, a three dimensional matrix is used to illustrate the scores of attributes, alternatives and time-sections. The tradeoff at different time-sections may be scored by decision makers is the major advantage of the proposed method. Finally, a numerical example is used to demonstrate the proposed method. The results display the helpfulness and facility of the proposed method for choosing an optimal 3PL company.

Keywords: Supplier selection, third party logistics (3PL), dynamic environment, fuzzy sets, analytic hierarchy process (AHP).

1. Introduction

Logistics is important for a manufacturing company in minimizing cost and maximizing the efficiency of resource use. Based on the trend of outsourcing, many third party logistics (3PL) companies provide a professional logistics service. In the global supply chain systems, industries try to outsource the logistics, and 3PL providers are one of the choices. Choosing the 3PL providers providing the best selection problems is an interesting and important subject of companies with face when trying to select a suitable and long-term 3PL company [1-4]. Thus, enterprises have to measure the performances of 3PL providers in flexible business.

Yan, et al. (2003) proposes a case-based reasoning model framework that is postulated for a 3PL evaluation and selection. Zhang et al. (2004) use the analytic hierarchy process (AHP) and data envelopment analysis methods to define a suitable 3PL company [5, 6]. But Zhang's method cannot measure the uncertainty or fuzziness of managers' judgments for vendors. Noorul Haq and Kannan issue the model by AHP and fuzzy AHP to demonstrate the vendor evaluation and selection in a supply chain [7]. Actually, decision makers always estimate the vendors' scores in linguistic terms. This method uses fuzzy sets to define the uncertainties of human judgments.

Saaty proposed the analytic hierarchy process (AHP) which is used in complex discrete multicriteria decision-making problems [8, 9]. Based on the pairwise comparisons of attributes and alternatives, the AHP derives relative preference measures for decision makers. Although Belton [10] and Dyer [11] raised some questions about the rationality of AHP's semantic scales and rank reversal, Vargas [12] and Wedley [13] distinguished three advantageous features of the differentiated AHP from other decision-making approaches: (1) its ability to handle both tangible and intangible attributes; (2) its ability to structure the problems in a hierarchical manner to gain insights into the decision-making process; (3) its ability to monitor the consistency with which a decision maker makes a judgment. The characteristics of AHP include simplicity, ease of use, flexibility, and the ability to handle complex and ill-structured problems; its principles have been applied successfully to many complex real-life decision-making problems [14]. In recent literatures, fuzzy sets are used for measuring the uncertainty in the systems. Based on fuzzy sets theory, Van Laarhoven and Pedrycz [15] extended Saaty's AHP method and estimated the scores of attributes and weights with triangular fuzzy numbers. However, this method suffers from three drawbacks [16, 17]: (1) the systems of triangular fuzzy numbers' linear equations are linear dependent and do not always have a solution; (2) the solution to the systems solution may not be a triangular fuzzy number; (3) the computational requirement for this approach is tremendous. Buckley [16] overcame the drawbacks of Laarhoven and Pedrycz's method and proposed using trapezoidal fuzzy numbers instead of triangular fuzzy numbers. Buckley's approach is based on a geometric mean method to derive fuzzy

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weights and scores. In addition, Chang [18] proposed using an extent analysis method instead of a logarithmic least squares method. Zhu, et al. [19] discussed two problems--"zero is used as divisor" and "data is out of range"--and provided the theoretical concept for Chang's method. Csutora and Buckley [20] devised the λ_{max} method to find the direct fuzzification of Saaty's λ_{max} method. Many scholars have studied the theory and applications of the fuzzy AHP method (e.g. [21-24]).

Few researchers have discussed the conditions under which the relative scores and weights of attributes and alternatives from estimating the decision makers' trade-offs can be changed for the time axis. But some literatures show decision makers try to discuss the influence of the past, present and future in their decision process. For example, Dickson [25] and Weber, et al. [26] suggest considering the historical scores of suppliers for vendor selection problem. But they do not issue the estimating method. In a recent study, Goetschalckx, et al. (2002) proposed managers can estimate the scores of the "near future" in global logistics systems. Chiang [27] also proposes a dynamic vendor selection method based on the AHP approach.

According to the above reviewed literatures, we believe the scores of vendors' past, present and near future work should be included in the decision process. But no existing method can fit this business scenario; therefore we modify fuzzy AHP to suit the fuzzy and dynamic decision situation.

In this paper, we define the dynamic decision environments as the decision maker's estimations which may be changed in different analytical time sections. The paper aims to demonstrate how to extend Buckley's fuzzy AHP and Chiang's dynamic method for 3PL vendor selection problem in uncertain and dynamic decision environments.

This paper is organized as follows: the proposed methods are introduced in Section 2. An empirical study of Taiwan as an example is illustrated to demonstrate the proposed framework with regard to its usefulness and validity in Section 3. Finally, based on the findings of this research, conclusions are presented in Section 4.

2. Proposed methods

For measuring the performance in dynamic and fuzzy business environment, we modify the fuzzy AHP to a multiple layer hierarchy. First, we illustrate the classical definition and arithmetic of the trapezoidal fuzzy number. Second, we define the notions of the trapezoidal fuzzy number. After this, we demonstrate the proposed method.

A. *The definition and Arithmetic of Trapezoidal Fuzzy Number*

Based on [28] and [16], we extend the definition and arithmetic of trapezoidal fuzzy number $\tilde{A}$ as any fuzzy subset of the real line R with membership function $f_{\tilde{A}}$ which possesses the following properties. $f_{\tilde{A}}$ is a continuous mapping from R to the closed interval [0, 1]. The values of $f_{\tilde{A}}$ on the horizontal axis can be described as

- $f_{\tilde{A}}(x)=0$, for all $x\in(-\infty,a]$;
- $f_{\tilde{A}}$ is strictly increasing on [a,b];
- $f_{\tilde{A}}(x)=1$, for all $x\in[b,c]$;
- $f_{\tilde{A}}$ is strictly decreasing on [c,d];
- $f_{\tilde{A}}(x)=0$, for all $x\in[d,\infty)$;

where a, b, c and d are real numbers.

The membership function $f_{\tilde{A}}$ of the fuzzy number $\tilde{A}$ can also be expressed as

$$f_{\tilde{A}}(x)=\begin{cases} f_{\tilde{A}}^{L}(x), & \text{if } a\le x\le b \\ 1, & \text{if } b\le x\le c \\ f_{\tilde{A}}^{R}(x), & \text{if } c\le x\le d \\ 0, & \textit{otherwise} \end{cases} \quad (1)$$

where $f_{\tilde{A}}^{L}(x)$ and $f_{\tilde{A}}^{R}(x)$ are the left and right membership functions of the fuzzy number $\tilde{A}$.

We use the trapezoidal fuzzy numbers form to define fuzzy membership function $f_{\tilde{A}}$ based on

$$f_{\tilde{A}}(x)=\begin{cases} (x-a)/(b-a), & \text{if } a\le x\le b \\ 1, & \text{if } b\le x\le c \\ (x-c)/(b-c), & \text{if } c\le x\le d \\ 0, & \textit{otherwise} \end{cases} \quad (2)$$

where a, b, c and d are real numbers.

The α-cut of fuzzy number $\tilde{A}$ can be defined as

$$\tilde{A}^{\alpha}=\left\{x \middle| f_{\tilde{A}}(x)\ge\alpha\right\} \quad \text{where } x\in R,\ \alpha\in[0,1]. \quad (3)$$

$\tilde{A}^{\alpha}$ is a non-empty bounded closed interval contained in R and it can be denoted by $\tilde{A}^{\alpha}=[\tilde{A}_l^{\alpha},\tilde{A}_u^{\alpha}]$, where $\tilde{A}_l^{\alpha}$ and $\tilde{A}_u^{\alpha}$ are the lower and upper bounds of the closed interval. Given fuzzy numbers $\tilde{A}$ and $\tilde{B}$, $\tilde{A},\tilde{B}\in R$, the α-cuts of $\tilde{A}$ and $\tilde{B}$ are $\tilde{A}^{\alpha}=[\tilde{A}_l^{\alpha},\tilde{A}_u^{\alpha}]$ and $\tilde{B}^{\alpha}=[\tilde{B}_l^{\alpha},\tilde{B}_u^{\alpha}]$, respectively. By interval arithmetic, the addition and multiplication of $\tilde{A}=(a_1,b_1,c_1,d_1)$ and $\tilde{B}=(a_2,b_2,c_2,d_2)$ can be expressed as [16]

$$(\tilde{A}\oplus\tilde{B})=(a_1+a_2,b_1+b_2,c_1+c_2,d_1+d_2) \quad (4)$$

$$(\tilde{A}\otimes\tilde{B})=(a[L_1,L_2],\ b,\ c,\ d[R_1,R_2]) \quad (5)$$

where

$$\begin{aligned} &a = a_1 \cdot a_2,\ b = b_1 \cdot b_2, \\ &c = c_1 \cdot c_2,\ d = d_1 \cdot d_2 \\ &L_1 = (b_1 - a_1)\cdot(b_2 - a_2), \\ &L_2 = a_2(b_1 - a_1) + a_1(b_2 - a_2), \\ &R_1 = (d_1 - c_1)\cdot(d_2 - c_2), \\ &R_2 = -[d_2(d_1 - c_1) + d_1(d_2 - c_2)]. \end{aligned} \tag{6}$$

$(\tilde{A} \oplus \tilde{B})$ is still the trapezoidal fuzzy number. But $(\tilde{A} \otimes \tilde{B})$ is no longer a trapezoidal fuzzy number. This means $f^L_{(\tilde{A}\otimes\tilde{B})}(x)$ and $f^R_{(\tilde{A}\otimes\tilde{B})}(x)$ are the curves.

B. *Notations*

The notations which describe the proposed method can be shown as follows. Fig. 1 shows a trapezoidal fuzzy number in different *k*.

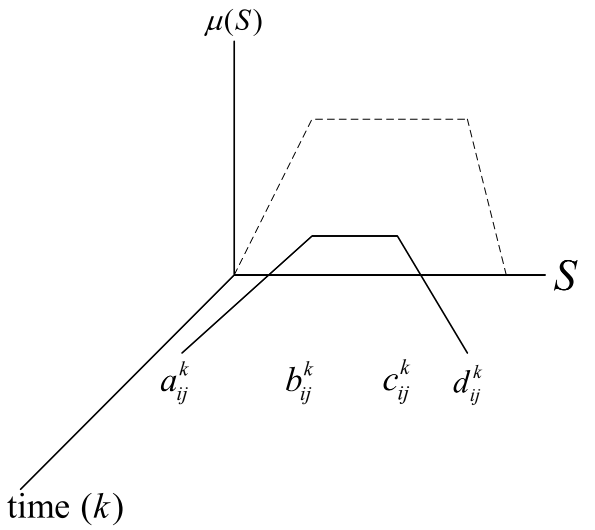

Fig. 1. The estimated score based on a trapezoidal fuzzy number in different *k*.

- A_q is the q^{th} possible alternative which decision makers have to choose, q=1, 2, …, m.
- C_i is the i^{th} attribute which decision makers choose for estimating the goal-achieving, i=1, 2, …, n.
- $\tilde{x}^k_{ij}$ is the relative estimative score of i^{th} attribute and j^{th} attribute for pairwise comparison of k^{th} time, $i, j \in \{1,2,...,n\}$; and $k = 1,2,...,p$. Fig. 1 shows each $\tilde{x}^k_{ij}$ can be described as a trapezoidal fuzzy number ($a^k_{ij}, b^k_{ij}, c^k_{ij}, d^k_{ij}$).
- $\tilde{x}^k_i$ is the geometric mean of $\tilde{x}^k_{ij}$, $i, j = \{1,2,...,n\}$; and $k = 1,2,...,p$. Each $\tilde{x}^k_i$ can be described as a trapezoidal fuzzy number ($a^k_i, b^k_i, c^k_i, d^k_i$).
- $\tilde{x}^k$ is the summation of $\tilde{x}^k_i$, i=1,2,…,n; and k=1,2,…,p. Each $\tilde{x}^k$ can be described as a trapezoidal fuzzy number (a^k, b^k, c^k, d^k).
- $\tilde{w}^k_i$ is the fuzzy weight in i^{th} at k^{th} time, i=1, 2, …, n, and k=1, 2, … , p.
- $\tilde{r}^k_{iq}$ is the absolute estimative performance score of i^{th} attribute of q^{th} alternative of k^{th} time, i=1, 2,…,n; q=1,2,…,m; and k=1,2,…, p.
- n is the number of criteria.
- m is the number of possible alternatives.
- p is the number of analytic time-periods.

C. *Concepts and Processes*

Traditionally decision-makers make an AHP structure using the goal, the pairwise comparison matrices of attributes, and the pairwise comparison matrices of alternatives. Decision makers always measure the pairwise comparisons subjectively. They do not think whether the scores of attributes may be changed by the dynamic business environment.

As Fig. 2 indicates, the decision-maker estimates the scores of each attribute and alternative in each time-period. The proposed method can be described in the following steps.

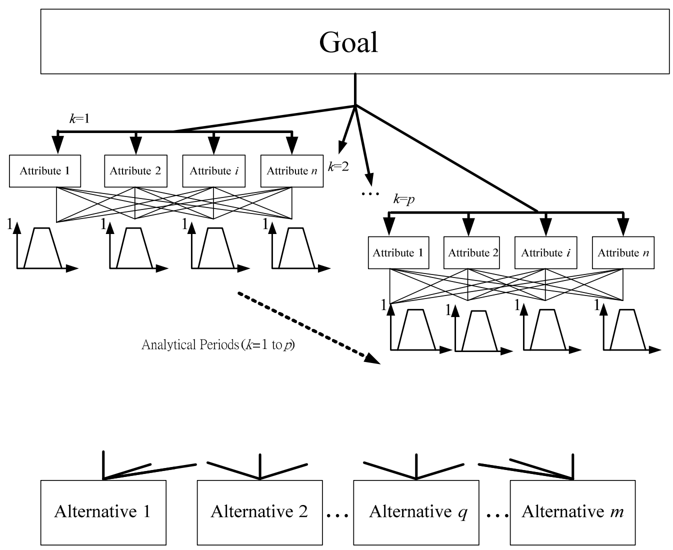

Fig. 2. Fuzzy AHP in dynamic decision environments.

Step 1. Estimating the relative comparison ratio $\tilde{x}^k_{ij}$, $\forall i, j, k$, takes trapezoidal fuzzy numbers ($a^k_{ij}, b^k_{ij}, c^k_{ij}, d^k_{ij}$).

Step 2. Testing inconsistency: Traditionally, AHP uses a consistency index (C.I.) and a consistency ratio (C.R.) to quantify the inconsistency of human judgment. In this paper, we suggest using a simple Centroid Method [17, 29, 30] to defuzzify the trapezoidal fuzzy number and test the inconsistency.

Step 3. Calculating the fuzzy weights $\tilde{w}_i^k$. The geometric mean for each row is determined as

$$\tilde{x}_i^k = \left(\prod_{j=1}^{n} \tilde{x}_{ij}^k \right)^{1/n} = \left(\tilde{x}_{i1}^k \otimes \cdots \otimes \tilde{x}_{ij}^k \otimes \cdots \otimes \tilde{x}_{in}^k \right)^{1/n}, \forall i,k, \tag{7}$$

where the sign $\otimes$ represents fuzzy multiplication as Eq(5).

The fuzzy weight $\tilde{w}_i^k$ is determined as

$$\tilde{w}_i^k = \tilde{x}_i^k \otimes (\tilde{x}_1^k \oplus \cdots \oplus \tilde{x}_n^k)^{-1}, \tag{8}$$

where the sign $\oplus$ represents fuzzy addition as Eq.(4).

Let the left leg $f_i^k(\alpha)$ and right leg $g_i^k(\alpha)$ of $\tilde{x}_{ij}^k$ be defined as

$$f_i^k(\alpha) = \left[\prod_{j=1}^{n} ((b_{ij}^k - a_{ij}^k)\alpha + a_{ij}^k) \right]^{1/n}, \ \alpha \in [0,1] \tag{9}$$

and

$$g_i^k(\alpha) = \left[\prod_{j=1}^{n} ((c_{ij}^k - d_{ij}^k)\alpha + d_{ij}^k) \right]^{1/n}, \ \alpha \in [0,1]. \tag{10}$$

Additionally, let $a_i^k = [\prod_{j=1}^{n} a_{ij}^k]^{1/n}$, $b_i^k = [\prod_{j=1}^{n} b_{ij}^k]^{1/n}$, $c_i^k = [\prod_{j=1}^{n} c_{ij}^k]^{1/n}$, $d_i^k = [\prod_{j=1}^{n} d_{ij}^k]^{1/n}$, $a^k = \sum_{i=1}^{n} a_i^k$, $b^k = \sum_{i=1}^{n} b_i^k$, $c^k = \sum_{i=1}^{n} c_i^k$, and $d^k = \sum_{i=1}^{n} d_i^k$. Similarly, the fuzzy weight $\tilde{w}_i^k$ is determined by Eq.(7).

Let s be a real number on the horizontal axis. The fuzzy membership function $\mu_{w_i}(s)$ can be summarized as Table 1. When $\mu_{w_i}(s) \notin \{0,1\}$, the s is calculated as

$$\begin{cases} s = \dfrac{f_i^k(\alpha)}{\sum_{i=1}^{m} g_i^k(\alpha)}, & \text{if } s \in [\dfrac{a_i^k}{d^k}, \dfrac{b_i^k}{c^k}], \\ s = \dfrac{g_i^k(\alpha)}{\sum_{i=1}^{m} f_i^k(\alpha)}, & \text{if } s \in [\dfrac{c_i^k}{b^k}, \dfrac{d_i^k}{a^k}]. \end{cases} \tag{11}$$

Table 1. The fuzzy membership function $\mu_{w_i}(s)$.

s	$\mu_{w_i}(s)$
$\le (\frac{a_i^k}{d^k})$	0
$[(\frac{a_i^k}{d^k}), (\frac{b_i^k}{c^k})]$	$\alpha \in [0,1]$
$[(\frac{b_i^k}{c^k}), (\frac{c_i^k}{b^k})]$	1
$[(\frac{c_i^k}{b^k}), (\frac{d_i^k}{a^k})]$	$\alpha \in [0,1]$
$\ge (\frac{d_i^k}{a^k})$	0

Step 4. Calculating the fuzzy performance scores $\tilde{r}_{iq}^k, \forall i,q,k$. The ratio $\tilde{r}_{iq}^k$ can be obtained as

$$\tilde{r}_{iq}^k = (\frac{a_{iq}^k}{d_i^k}, \frac{b_{iq}^k}{c_i^k}, \frac{c_{iq}^k}{b_i^k}, \frac{d_{iq}^k}{a_i^k}). \tag{12}$$

Actually, $\tilde{r}_{iq}^k$ is the normalized score for each attribute, alternative, and time-period.

Step 5. Calculating the score for each alternative for each time-period. The fuzzy utilities of k^{th} time for alternative $\tilde{u}_q^k, \forall q,k,$ are calculated based on

$$\tilde{u}_q^k = \sum_{i=1}^{n} (\tilde{w}_i^k \otimes \tilde{r}_{iq}^k). \tag{13}$$

Step 6. Calculating the fuzzy scores for each time-period. The final fuzzy scores for each alternative $\tilde{u}_q, \forall q$ are calculated based on

$$\tilde{u}_q = \sum_{k=1}^{p} \tilde{u}_q^k . \tag{14}$$

Step 7. Rating and making the contracts. By Eq.(14), managers can rate the top one or two vendors to make the contracts. The clauses of contracts should be better than the proposed articles from vendors by reducing gaps for achieving the best win-win selection.

D. *Reducing Gaps for Achieving the Best Win-win Selection*

In the proposed method, we suggest the companies should select the best two vendors which can reduce the gaps $\hat{\tilde{u}}_q$ between real value $\tilde{u}_q$ and aspired value $\tilde{u}_q^*$ in q alternative, and the gap $\hat{\tilde{r}}_{iq}^k$ between $\tilde{r}_{ij}^k$ and $\tilde{r}_{iq}^{*k}$ for each criterion i^{th} of alternative q^{th}. We define the gaps $\hat{\tilde{u}}_q$ and $\hat{\tilde{r}}_{iq}^k$ as

$$\hat{\tilde{u}}_q^k = \sum_{i=1}^{n} (\tilde{w}_i^k \otimes \hat{\tilde{r}}_{iq}^k) \text{ and } \hat{\tilde{u}}_q = \sum_{k=1}^{p} \hat{\tilde{u}}_q^k \quad (15)$$

where $\hat{\tilde{r}}_{iq}^{*k} = \max \tilde{r}_{iq}^k, \forall i,q,k$ or setting the aspired level $\hat{\tilde{r}}_{iq}^{*k}$ by decision maker.

Actually, the proposed method is a two-stage decision method. In stage 1, we used 3D fuzzy AHP method to find two alternatives. In stage 2, we can reduce the gaps for achieving the best win-win selection by negotiating with two vendors in fuzzy dynamic decision environments.

3. An Empirical Study of Taiwan as an Illustrative Example

Based on 2005 and 2006 Taiwan Logistics Yearbook [31, 32], the output value of logistics industry is over USD 40 billion and the numbers of employees are over 200,000. The competitive market makes the transition fast in logistics industry. Based on some enterprises investigations, we believe decision makers try to consider the dynamic and fuzzy decision environments to adapt to the fast changed industry. In this section, we demonstrate an empirical study of Taiwan to select a suitable 3PL company as an illustrative example in fuzzy dynamic decision environments.

A. *Problem Descriptions*

For illustrating the proposed method, we investigate some enterprises and assume a numerical business condition. A manufacturer tries to select a 3PL company for outsourcing the logistics between Taiwan and Mainland China. The Purchasing Department organizes a committee (including 3 managers, 2 consultants and 2 employees) to select a suitable logistics provider and make the contract. Thus, we build a group decision problem. The frame of the attributes in this study can be described as the follows. Dickson proposed 23 attributes and the ranking as quality, delivery, performance history, warranties and claim policies, production facilities and capacity, price, technical capability, financial position, procedural compliance, communication system, reputation and position in industry, desire for business, management and organization, operating controls, repair service, attitude, impression, packaging ability, labor relation record, geographical location, amount of past business, training aids, and reciprocal arrangement [25]. In recent literature, information technique has been one of the most important criteria to measure a 3PL company [33]. The information technique can make logistics companies improve service quality, procedural compliance, communication system, operating controls, training aids, and reciprocal arrangement. Besides, flexible response to special orders is also an important criterion to service the customers. Therefore, we suggest making the main hierarchy price, delivery performance, information technique ability, and flexible response to special orders. The attributes of logistics vendor selection are discussed in [5, 34-39].

After structuring the analytic hierarchy, the decision makers want to rank 3PL providers A_1, A_2, and A_3, with respect to four attributes, C_1= price, C_2= delivery performance, C_3= information technique ability, and C_4= flexible response to special orders. The analytic time sections are the past (k=1), now (k=2), and near future (k=3). Thus, the decision makers can estimate the relative weights ratios for each pair of alternatives under every attribute as well as the relative weights ratios for the attributes. The equal weighting average method is used to integrate the judgments of decision makers. The results can be described in the following five pairwise comparison matrices as Table 2-6.

Table 2. The estimative scores of C_1 at k=1, 2, and 3 in each alternative.

C_1 at k =1	A_1	A_2	A_3
A_1	1	(1/4,1/3,1/3,1/2)	(2, 3, 6, 8)
A_2	(2, 3, 3, 4)	1	(8, 8, 8, 8)
A_3	(1/8, 1/6, 1/3, 1/2)	(1/8, 1/8, 1/8, 1/8),	1
C_1 at k =2			
A_1	1	(1/4,1/2,1/2,1/2)	(3, 4, 4, 5)
A_2	(2, 2, 2, 4)	1	(8, 8, 8, 8)
A_3	(1/5, 1/4, 1/4, 1/3)	(1/8, 1/8, 1/8, 1/8)	1
C_1 at k = 3			
A_1	1	(1/2,1/2,1/2,1/2)	(1, 2, 3, 4)
A_2	(2, 2, 2, 2)	1	(4, 5, 6, 7)
A_3	(1/4, 1/3, 1/2, 1)	(1/7, 1/6, 1/5, 1/4)	1

Table 3. The estimative scores of C_2 at k=1, 2, and 3 in each alternative.

C_2 at k =1	A_1	A_2	A_3
A_1	1	(1, 2, 2, 3)	(2, 4, 4, 6)
A_2	(1/3,1/2,1/2,1)	1	(1, 2, 2, 3)
A_3	(1/6,1/4,1/4,1/2)	(1/3,1/2,1/2,1)	1
C_2 at k =2			
A_1	1	(2, 4, 4, 6)	(4, 5, 5, 6)
A_2	(1/6,1/4,1/4,1/2)	1	1
A_3	(1/6,1/5,1/5,1/4)	1	1
C_2 at k = 3			
A_1	1	(3, 4, 5, 6)	(2, 3, 3, 4)
A_2	(1/6,1/5,1/4,1/3)	1	1
A_3	(1/4,1/3,1/3,1/2)	1	1

Table 4. The estimative scores of C_3 at k=1, 2, and 3 in each alternative.

C_3 at k =1	A_1	A_2	A_3
A_1	1	(1/6, 1/5, 1/5, 1/4)	(1/3, 1/2, 1/2, 1)
A_2	(4, 5, 5, 6)	1	(1, 2, 2, 3)
A_3	(1, 2, 2, 3)	(1/3, 1/2, 1/2, 1)	1
C_3 at k =2			
A_1	1	(1/6, 1/5, 1/5, 1/4)	(1/2, 1/2, 1/2, 1/2)
A_2	(4, 5, 5, 6)	1	(1, 2, 2, 3)
A_3	(2, 2, 2, 2)	(1/3, 1/2, 1/2, 1)	1
C_3 at k = 3			
A_1	1	(1/4, 1/3, 1/3, 1/2)	(1/2, 1/2, 1/2, 1/2)
A_2	(2, 3, 3, 4)	1	1
A_3	(2, 2, 2, 2)	1	1

Table 5. The estimative scores of C_4 at k=1, 2, and 3 in each alternative.

C_4 at k =1	A_1	A_2	A_3
A_1	1	(1/3,1/2,1/2,1)	(1, 3, 3, 5)
A_2	(1, 2, 2, 3)	1	(6, 7, 7, 8)
A_3	(1/5, 1/3, 1/3, 1)	(1/8,1/7,1/7,1/6)	1
C_4 at k =2			
A_1	1	(1/7,1/6,1/5,1/4)	(1, 2, 2, 3)
A_2	(4, 5, 6, 7)	1	(7, 8, 8, 9)
A_3	(1/3, 1/2, 1/2, 1)	(1/9,1/8,1/8,1/7)	1
C_4 at k = 3			
A_1	1	(1/8,1/7,1/6,1/5)	(1/3, 1/2, 1/2, 1)
A_2	(5, 6, 7, 8)	1	(2, 3, 3, 4)
A_3	(1, 2, 2, 3)	(1/4,1/3,1/3,1/2)	1

B. *Analyses and results*

For each pairwise comparison matrix, the geometric mean is calculated based on Eq. (6). By Eq. (13), the normalization of $\tilde{x}_{ij}^k$ can be shown as $\tilde{r}_{iq}^k$. After normalization, the decision matrixes can be shown as Table 7 and Table 8.

Based on Eq. (9), the total scores at k=1, 2, and 3 for each alternative can be calculated; the total performance is shown as Table 9. And the parameters and diagram of the final fuzzy utility function of A_1, A_2, and A_3 can be shown as Table 10 and Fig. 3.

Based on Table 9, we can distinguish the utilities of three alternatives in three analytical time sections. Fig. 3 shows the result of the final fuzzy utility to be $A_2 \geq A_1 \geq A_3$.

After ranking the alternatives, the Purchasing Department negotiates with A_2 and A_1 to have a better contract. A_2 and A_1 reduce the prices. And the fuzzy performance index are A_2 (0.8, 1.7, 2.5, 5) and A_1 (0.5, 1.0, 1.5, 3.0).

Table 6. The estimative scores of weights at k=1,2,and 3 in each attribute.

k=1	C_1	C_2	C_3	C_4
C_1	1	(6, 7, 8, 9)	(5, 6, 6, 7)	(3, 4, 4, 5)
C_2	(1/9, 1/8, 1/7,1/6)	1	(1, 2, 3, 4)	(2, 3, 3, 4)
C_3	(1/7, 1/6, 1/6,1/5)	(1/4, 1/3, 1/2,1)	1	(1/3,1/2,1/2,1)
C_4	(1/5, 1/4, 1/4,1/3)	(1/4, 1/3, 1/3,1/2)	(1, 2, 2, 3)	1
k=2				
C_1	1	(4, 5, 6, 7)	(3, 4, 4, 5)	(3, 4, 4, 5)
C_2	(1/7, 1/6, 1/5,1/4)	1	(1, 2, 2, 3)	(1, 2, 2, 3)
C_3	(1/5, 1/4, 1/4,1/3)	(1/3, 1/2, 1/2,1)	1	1
C_4	(1/5, 1/4, 1/4,1/3)	(1/3, 1/2, 1/2,1)	1	1
k=3				
C_1	1	(4, 5, 6, 7)	(2, 3, 4, 5)	(1, 2, 3, 4)
C_2	(1/7, 1/6, 1/5,1/4)	1	(1/3,1/2, 1/2, 1)	(1, 2, 3, 4)
C_3	(1/5, 1/4, 1/3,1/2)	(1, 2, 2, 3)	1	(1/4, 1/3,1/2,1)
C_4	(1/4, 1/3, 1,1)	(1/4, 1/3, 1/2,1)	(1, 2, 3, 4)	1

Table 7. The normalized scores of each attribute and alternative.

$\tilde{r}_{iq}^k$	a	b	c	d
i=1, j=1, k=1, 2, 3	0.154, 0.186, 0.185	0.223, 0.308, 0.257	0.303, 0.308, 0.324	0.433, 0.365, 0.403
i=1, j=2, k=1, 2, 3	0.508, 0.516, 0.465	0.642, 0.615, 0.553	0.693, 0.615, 0.647	0.866, 0.853, 0.772
i=1, j=3, k=1, 2, 3	0.048, 0.060, 0.077	0.061, 0.077, 0.098	0.083, 0.077, 0.131	0.108, 0.093, 0.202
i=2, j=1, k=1, 2, 3	0.259, 0.423, 0.416	0.571, 0.656, 0.604	0.571, 0.656, 0.691	1.122, 1.065, 1.587
i=2, j=2, k=1, 2, 3	0.143, 0.116, 0.126	0.286, 0.152, 0.154	0.286, 0.152, 0.177	0.618, 0.256, 0.381
i=2, j=3, k=1, 2, 3	0.079, 0.116, 0.144	0.143, 0.192, 0.183	0.143, 0.192, 0.194	0.340, 0.203, 0.437
i=3, j=1, k=1, 2, 3	0.081, 0.100, 0.144	0.128, 0.128, 0.169	0.128, 0.128, 0.169	0.237, 0.173, 0.209
i=3, j=2, k=1, 2, 3	0.338, 0.362, 0.362	0.595, 0.595, 0.443	0.595, 0.595, 0.443	0.985, 0.904, 0.525
i=3, j=3, k=1, 2, 3	0.148, 0.199, 0.362	0.276, 0.276, 0.387	0.276, 0.276, 0.387	0.542, 0.435, 0.417
i=4, j=1, k=1, 2, 3	0.135, 0.097, 0.071	0.292, 0.145, 0.102	0.292, 0.163, 0.112	0.610, 0.233, 0.187
i=4, j=2, k=1, 2, 3	0.353, 0.561, 0.439	0.615, 0.717, 0.644	0.615, 0.806, 0.706	1.029, 1.022, 1.014
i=4, j=3, k=1, 2, 3	0.057, 0.062, 0.128	0.092, 0.083, 0.215	0.092, 0.088, 0.224	0.196, 0.134, 0.366

Table 8. The normalized weights of w_i^k.

w_i^k	a	b	c	d
i=1, k=1, 2, 3	0.440, 0.384, 0.242	0.612, 0.568, 0.424	0.667, 0.616, 0.677	0.922, 0.891, 1.102
i=2, k=1, 2, 3	0.098, 0.096, 0.067	0.158 , 0.172, 0.116	0.191, 0.186, 0.172	0.280, 0.300, 0.320
i=3, k=1, 2, 3	0.047, 0.080, 0.068	0.069, 0.113, 0.116	0.081, 0.117, 0.177	0.146, 0.186, 0.354
i=4, k=1, 2, 3	0.068, 0.080, 0.072	0.109, 0.113, 0.124	0.115, 0.117, 0.257	0.184, 0.186, 0.453

Table 9. The total scores at k=1, 2, and 3 for each alternative.

Alternative	k	a^k	L_1^k	L_2^k	b^k	c^k	d^k	R_1^k	R_2^k
	1	0.106	0.038	0.123	0.267	0.355	0.860	0.111	-0.616
A_1	2	0.128	0.043	0.148	0.319	0.346	0.720	0.070	-0.445
	3	0.088	0.025	0.099	0.211	0.397	1.111	0.188	-0.902
	1	0.277	0.048	0.221	0.546	0.636	1.305	0.128	-0.796
A_2	2	0.283	0.034	0.207	0.524	0.571	1.195	0.114	-0.738
	3	0.191	0.043	0.200	0.435	0.800	1.811	0.186	-1.197
	1	0.040	0.010	0.039	0.089	0.116	0.310	0.048	-0.243
A_3	2	0.055	0.012	0.050	0.117	0.126	0.250	0.020	-0.144
	3	0.062	0.016	0.067	0.145	0.262	0.709	0.103	-0.550

Table 10. The parameters of the fuzzy utility function of A_1, A_2, and A_3.

Alternative	a	L_1	L_2	b	c	d	R_1	R_2
A_1	0.322	0.106	0.370	0.797	1.098	2.691	0.369	-1.963
A_2	0.751	0.125	0.628	1.505	2.007	4.311	0.428	-2.731
A_3	0.157	0.038	0.156	0.351	0.504	1.269	0.171	-0.937

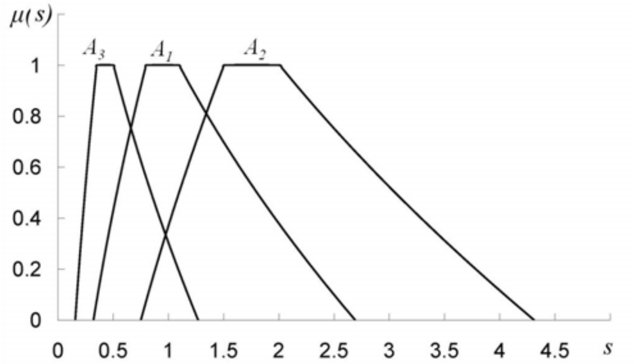

Fig. 3. The fuzzy utility function of A_1, A_2, and A_3.

Finally, the performance of the contract by A_2 is (0.8, 1.7, 2.5, 5) which is better than the original score of A_2 (0.751, 1.505, 2.007, 4.311).

C. *Discussions*

In logistics management, every company optimizes the upstream members (vendors) and downstream members (customers) for better operating performance. Even companies may share the private information with the cooperative enterprises for optimizing the performance of the entire supply chain. In our case, three alternatives are judged for better selection. The group decision members select the best partner based on book data. After negotiating with two alternatives, the acquisition is better than book data. This means we can reduce the gaps between $\tilde{u}_q$ and desirable value $\hat{\tilde{u}}_q$ in q alternative, and between $\tilde{r}_{iq}^k$ and $\hat{\tilde{r}}_{iq}^k$.

The major advantage of the proposed method is decision makers can distinguish the utilities of different alternatives in different analytical time sections as Table 2-5 and know the final performance scores. This improvement can prevent decision makers from only considering only one analytical time section. Besides, fuzzy membership functions can score the uncertainty of weights as Table 6. Table 8 shows the price is still the most important attribute in the analytical framework in different time-periods.

We use Buckley's method to define the multiplication of the trapezoidal fuzzy number. The left and right membership functions are curves. This can make the differences in different alternatives clearer. However, in this method, if the trend of all the criteria scores is identical, the final result is the same as the result of each analytical time section. In some rapidly changing industries, the scores of attributes always change quickly in different analytical time periods.

4. Conclusions

This paper extends the fuzzy analytic hierarchy process method for solving the third party logistics supplier selection problem in dynamic and uncertain environments. We proposed a two-stage decision method for the win-win selection in supply chain management. Based on the proposed method, decision makers can estimate 3PL companies by different scores in different analytic time sections. This allows decision makers to distinguish the utilities of different alternatives in the past, present and near future and know the entire performance scores. The numerical examples show the helpfulness and facility of the proposed method for choosing an optimal 3PL company.

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